



Developing Controlled Conductive Boundaries for JWST Cryogenic Testing

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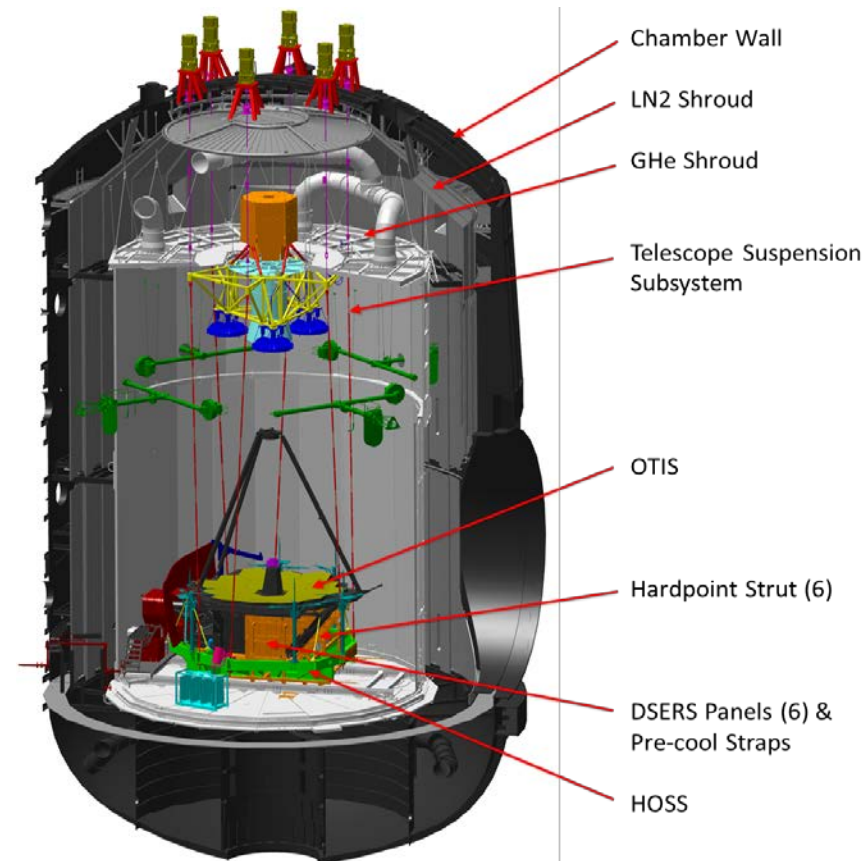
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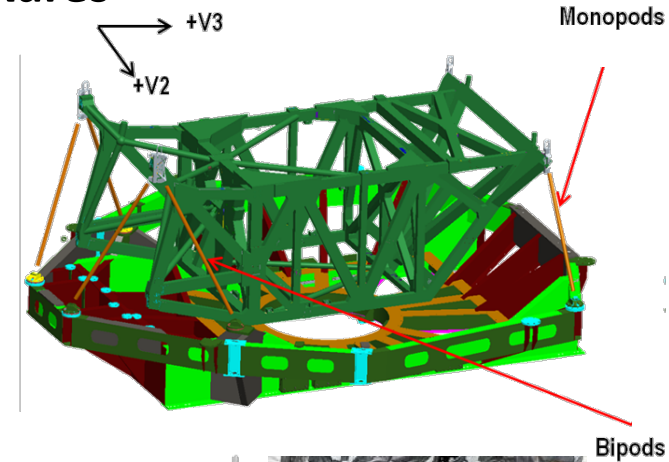
- **The James Webb Space Telescope (JWST) completed cryogenic testing in the fall of 2017**
 - Final thermal test of Optical Telescope Element + Integrated Science Instruments Module (OTIS)
- **Thermal objectives for OTIS test:**
 - Verify system thermal workmanship
 - Validate thermal model with test data
 - Verify instrument heat loads within 10% of model predictions
- **Harris Thermal Role**
 - Thermal control of ground support equipment (GSE) boundary conditions
 - Keep OTIS heat loads and temperatures flight-like
 - Accelerate test schedule while obeying all limitations and constraints



Hardpoint struts

■ 6 carbon fiber composite struts with MP35N flexures

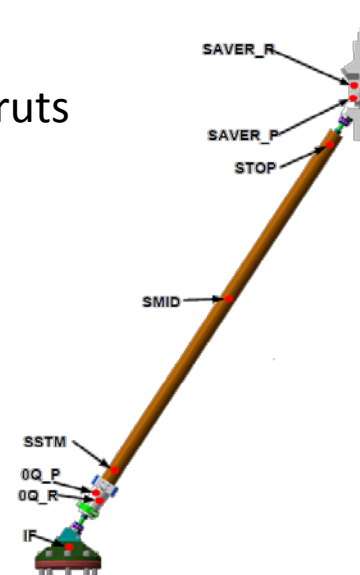
- Supports OTIS for the 1-G environment
 - Deviates from the flight condition
- Bipod arrangement on $-V3$ end, Monopod at $+V3$
- 25-layer MLI blankets on outside keep radiative effects low



■ Heat leakage requirements

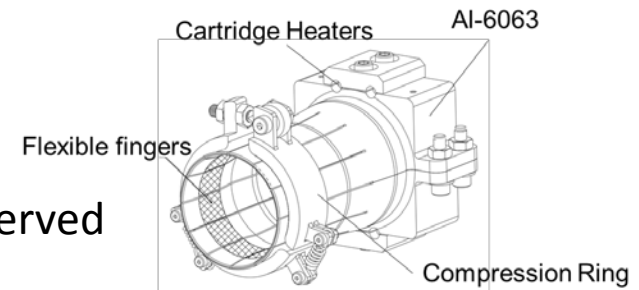
- 2 mW on monopod struts, 6 mW on bipod struts
- More heat is acceptable at the bipods due to the warm Core Area on $-V3$ end of OTIS

Even with low conduction and insulated struts, active thermal control was required to meet heat leakage requirements



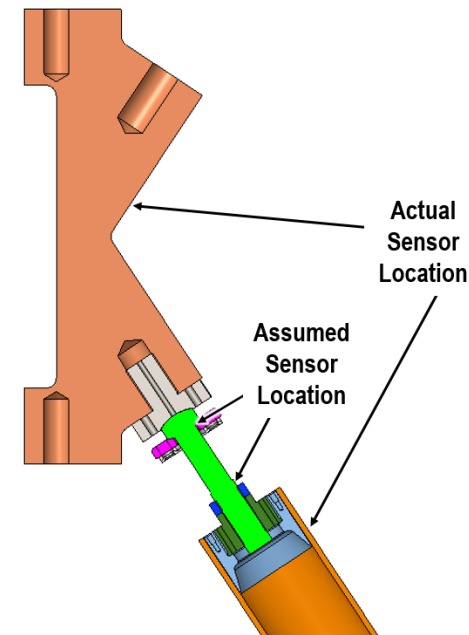
- **6 heaters were designed to mount at base of each strut**

- Al-6063 heater block
- Flexible fingers and compression ring maintain clamping loads at struts
 - As the aluminum shrinks, contact pressure is preserved



- **Calculating heat flow**

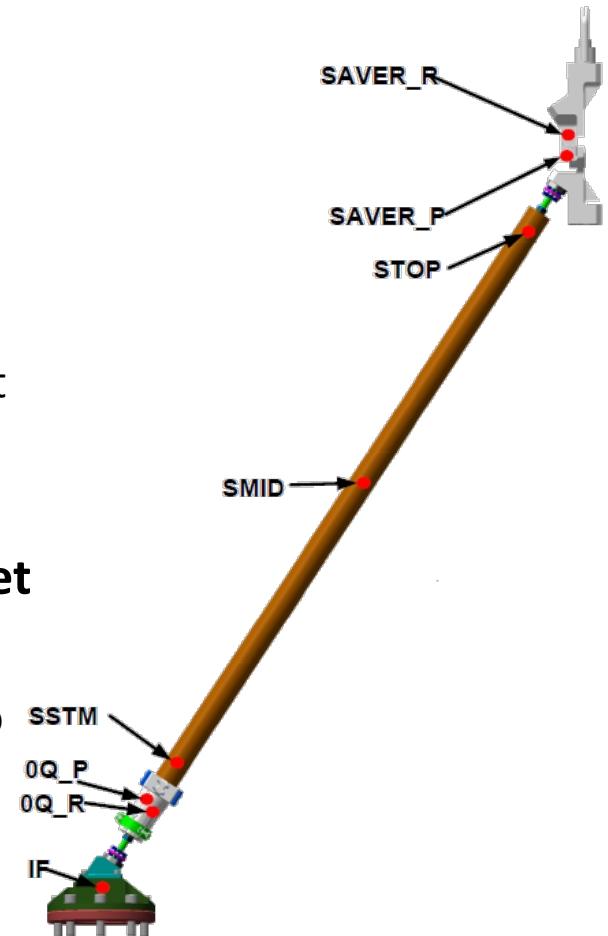
- The difference in temperature across the flexure at the top of the strut is used
- $$Q = \frac{kA}{L} (T_{Saver} - T_{STOP})$$
- Discrete heat path
 - Small area limits errors from radiation
 - Conservatism in calculation based on actual sensor locations



Heater Operation

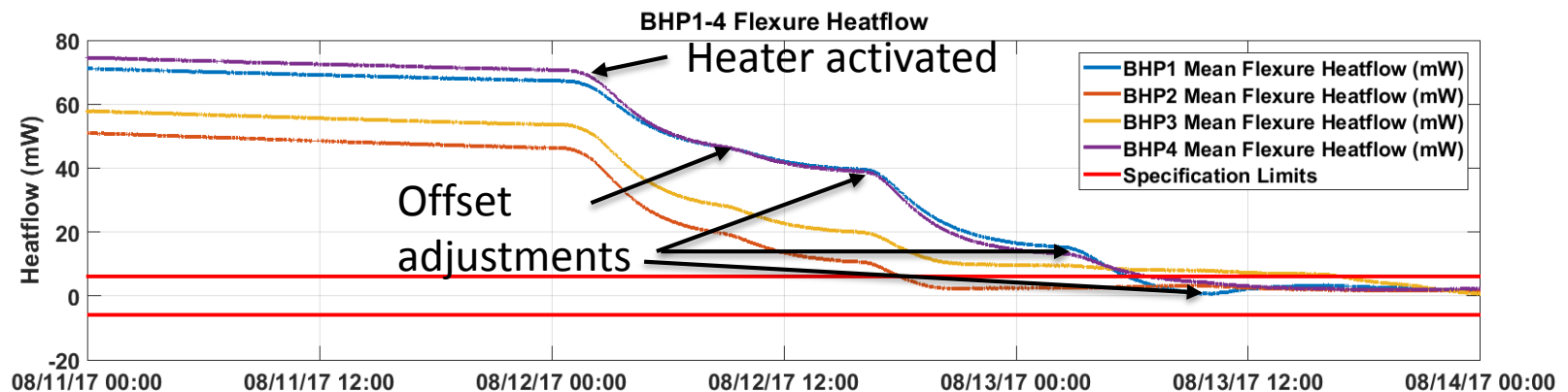
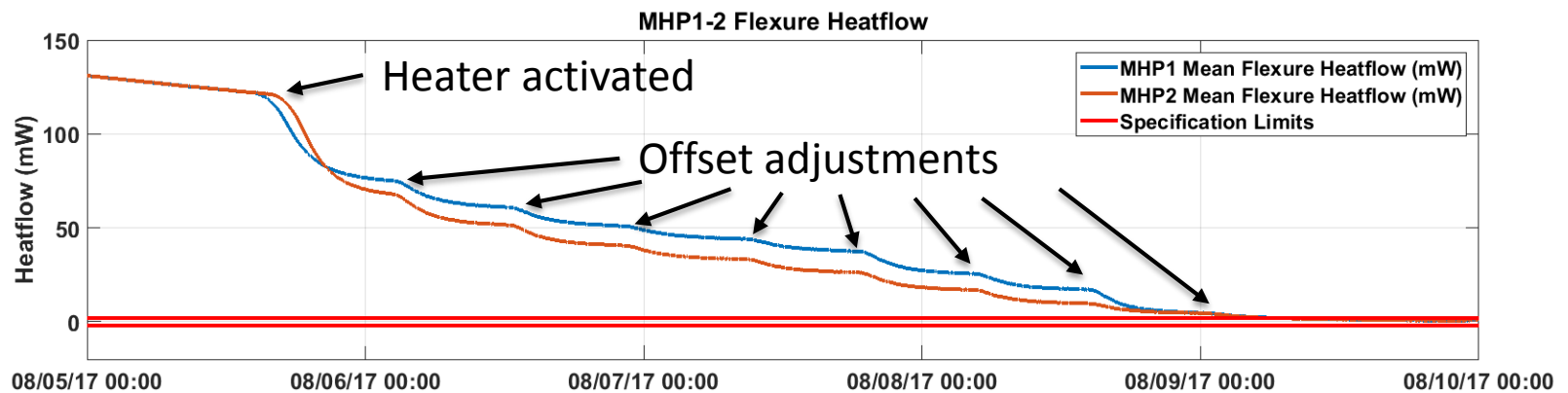
- A semi-automated routine was configured in the test set for changing setpoints during cooldown
- The 0-Q heater applies heat such that the temperature at
STOP = SAVER_P
 - With zero gradient across the flexure, there is no heat transfer
- The test set enabled the setpoint of the heater to be the current temperature of SAVER_P + an offset
 - Heater setpoint gets updated every 2 minutes
 - User supplied offset modified to trim the heat flow to zero

The updating setpoint was able to track the cooldown of OTIS while keeping heat leakage small



Hardpoint Strut

- Monopod 0-Q heaters activated 8/5 when saver plate reached 65K
- Bipod 0-Q heaters activated 8/12 after thermal distortion testing



Pre-cool Straps

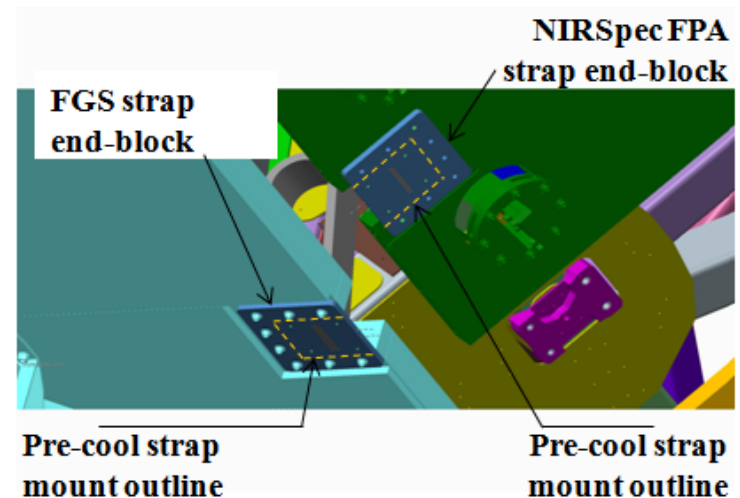
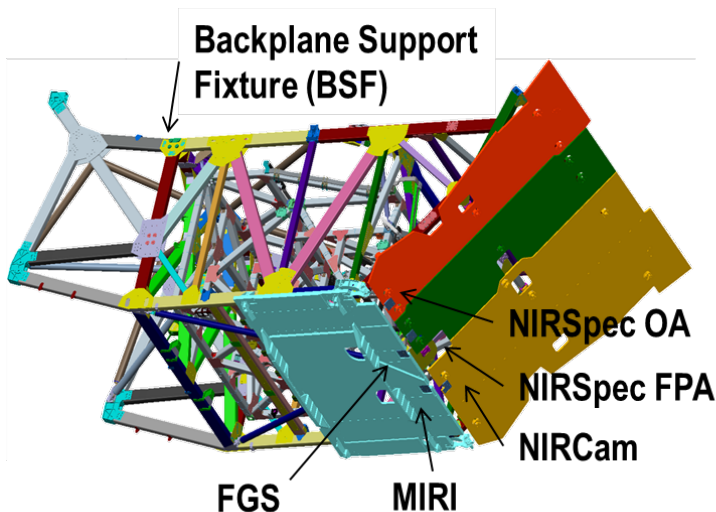
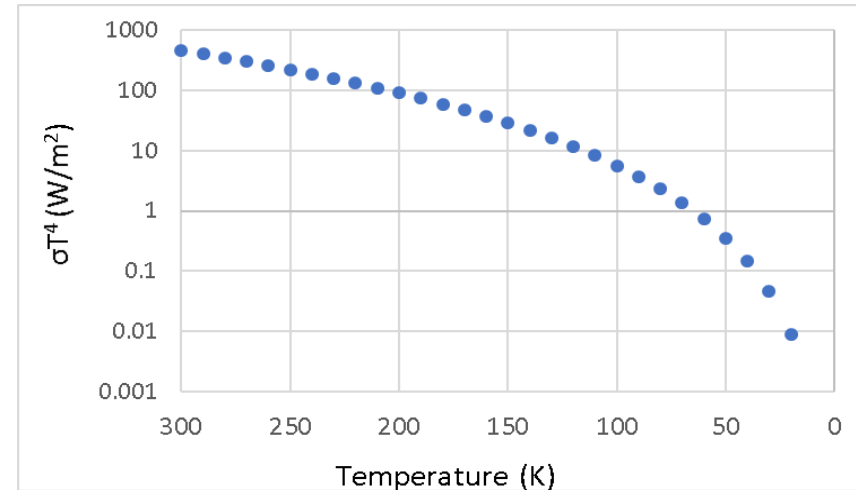
■ Critical functions

- Accelerate cooldown for science instruments with a link to a cold sink
 - Below 100K, radiation drops off
- Stop conduction or “O-Q” the straps once at operating temp

■ 5 Locations

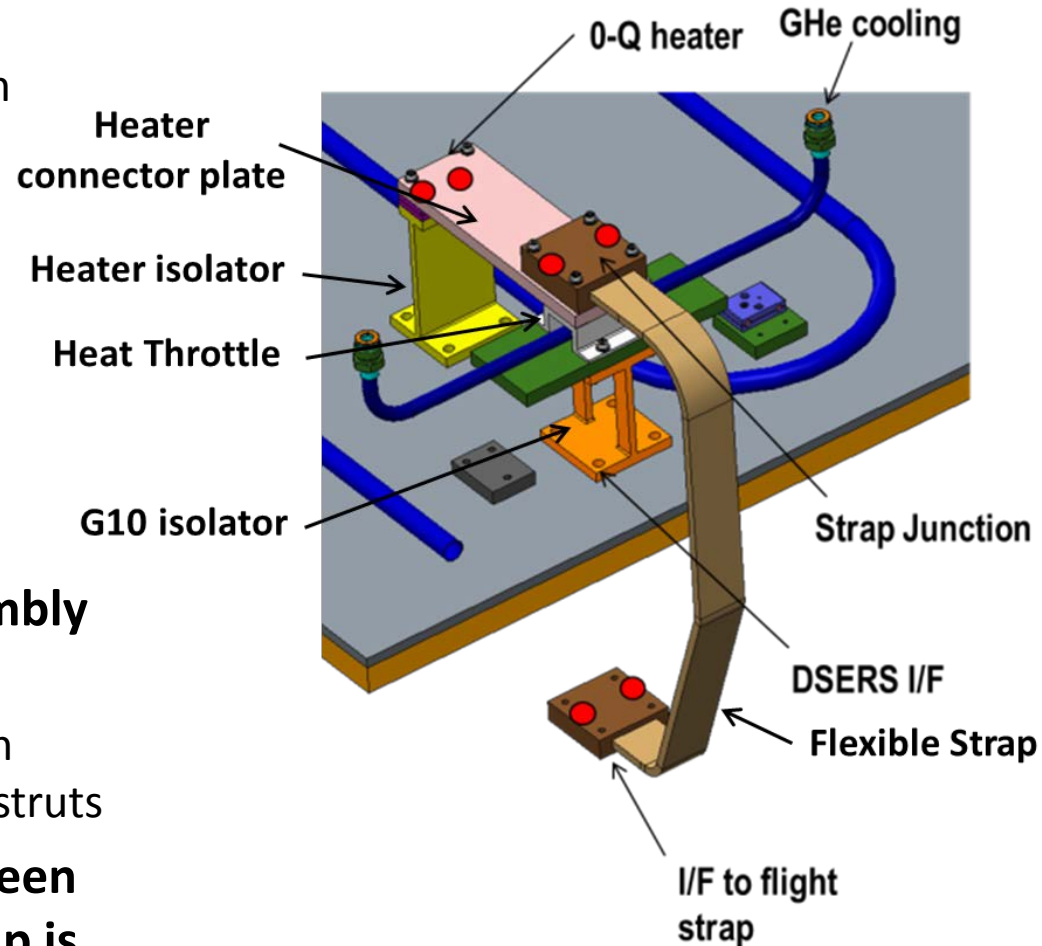
- Mount to heat strap end blocks at radiators

Potential heat flux vs. temperature

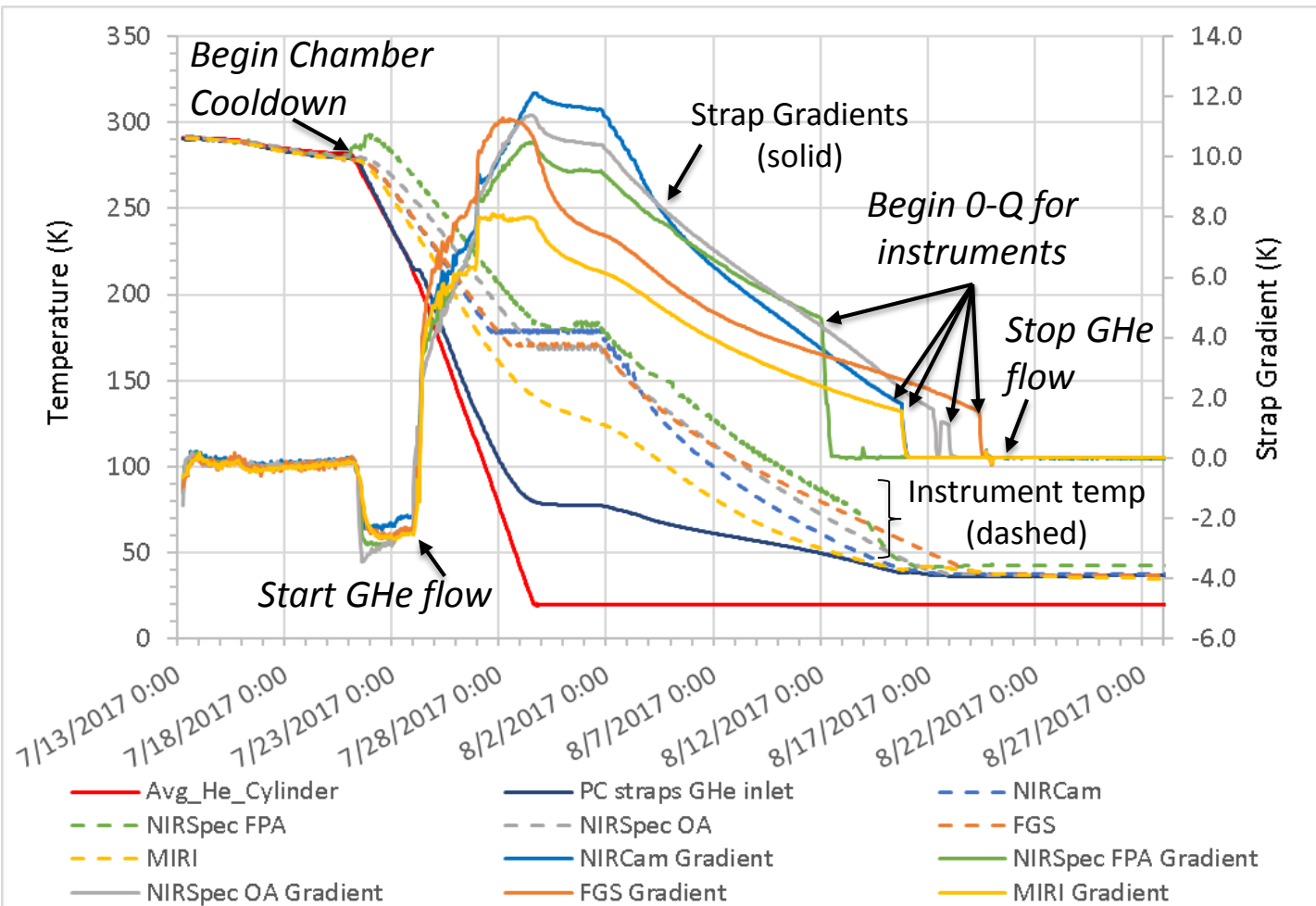


Detailed Design

- **High purity aluminum strap**
 - Accommodates relative motion from OTIS to support structure
- **GHe tube under the strap serves as a cold sink**
 - GHe flows during cooldown, shuts off for 0-Q phase
 - Conduction path optimized to throttle heat flow
- **0-Q heater located at end of assembly for precision control**
 - 0-Q heater designed to perform with automated setpoints like hardpoint struts
- **0-Q achieved when gradient between strap junction and I/F to flight strap is zero**

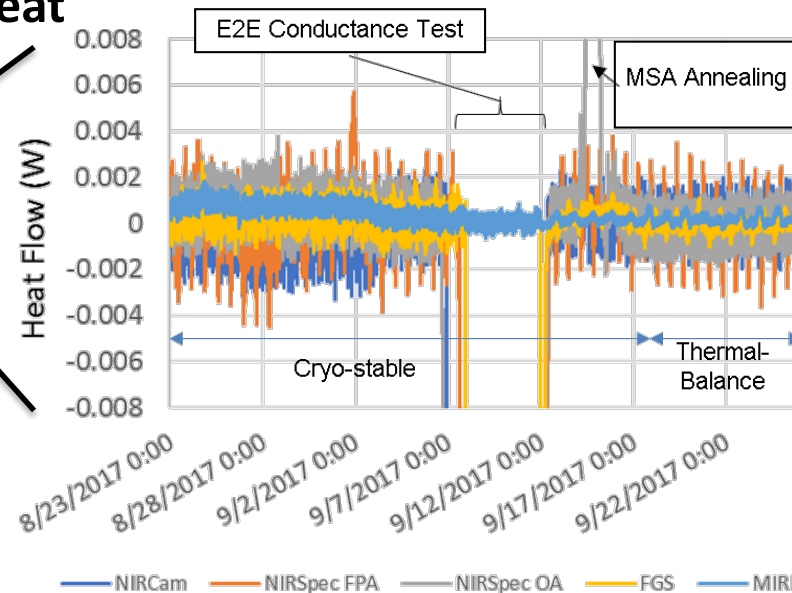
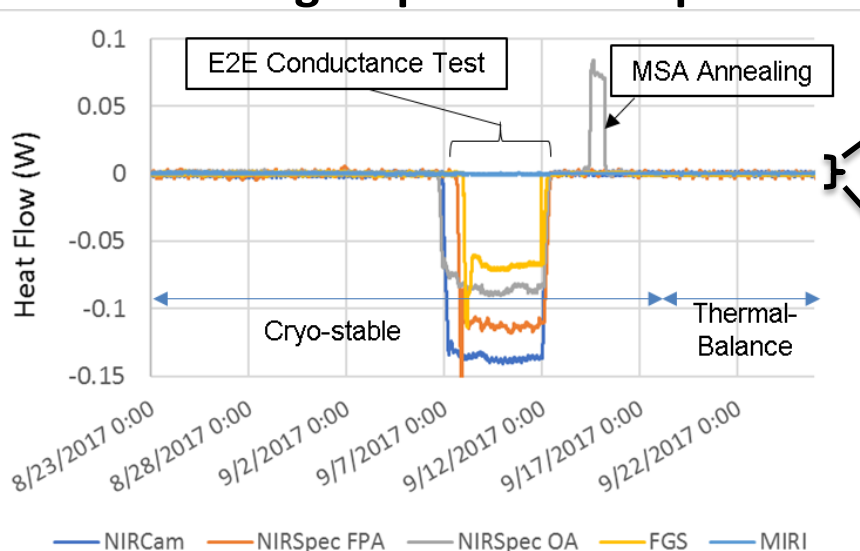


Cooldown Timeline



- 7/13 Chamber pumpdown
- 7/21 Start of cooldown
- 7/24 Start GHe flow to pre-cool straps
- 8/11 NIRSpec FPA 0-Q started
- 8/15 NIRCam and MIRI 0-Q started
- 8/17 NIRSpec OA 0-Q started
- 8/19 FGS 0-Q started
- 8/19 GHe flow stopped to pre-cool straps

- After the GHe flow was stopped, heater setpoint offsets were adjusted down to resolutions of 0.05K to 0.025K
- Heat flow variations were small, but from 9/7-9/12 was the E2E Conductance Test
 - 0-Q heaters were used to push the strap interface up to 40K, driving heat out (negative value) of the strap
- On 9/14 the planned microshutter annealing for NIRSpec OA took place, causing its pre-cool strap to remove heat





0-Q Performance



- **All 5 pre-cool straps kept heat flows near 0 W**
 - Some spikes in heat flows, with largest on NIRSpec FPA
 - Corresponds with instrument system heater power/dissipation signature
 - Attempts to correct for the spikes were detrimental to the other direction of the oscillation
- **Heat leakages for 0-Q periods (excludes E2E Conduction and MSA Annealing tests) are shown in the table**
 - Negative values are heat flow out of OTIS, positive values are heat flow into OTIS
 - Heat from temperature uncertainty shows uncertainty from sensor calibration

	Average Heat Leak (mW)	Maximum Heat Leak (mW)	Minimum Heat Leak (mW)	Standard Deviation (mW)	Heat from temp. uncertainty (mW)
NIRCam	-0.39	1.95	-2.85	0.82	1.84
NIRSpec FPA	-0.08	5.70	-4.24	1.31	2.13
NIRSpec OA	0.29	2.75	-1.58	0.71	2.89
FGS	0.18	2.03	-0.84	0.45	1.68
MIRI	0.47	1.29	-0.22	0.33	3.02





Lessons Learned



- **Using engineering models and interface simulators can significantly burndown risk**
 - The Thermal Pathfinder Test before OTIS Testing helped to commission the systems and characterize responses
- **Communication between test teams and across organizations is crucial for a successful test**
 - Forewarnings can go a long way for anticipating future effects
- **Any time devoted for sensor calibrations or heater control parameters (PID) need to be scheduled into the test and planned for**
 - Calibrations or determining system settings can take time (and require specific environments)





Conclusion



- **In 2017, the hardpoint struts and pre-cool straps thermally managed OTIS interfaces in order to:**
 - Keep temperatures and heat flows flight-like
 - Accelerate test schedule
- **The hardpoint struts, the main structural offloading points to OTIS were used to manage heat flows**
 - Zeroed the gradient across flexure interface to < 6 mW for bipods and < 2 mW for monopods
- **The pre-cool straps interfaced to the end blocks of the flight heat straps and successfully**
 - Removed heat from the instruments when radiative heat transfer diminishes for cooldown
 - During the critical thermal balance period, heat flows were minimized to a few mW of heat leakage





Acknowledgments



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